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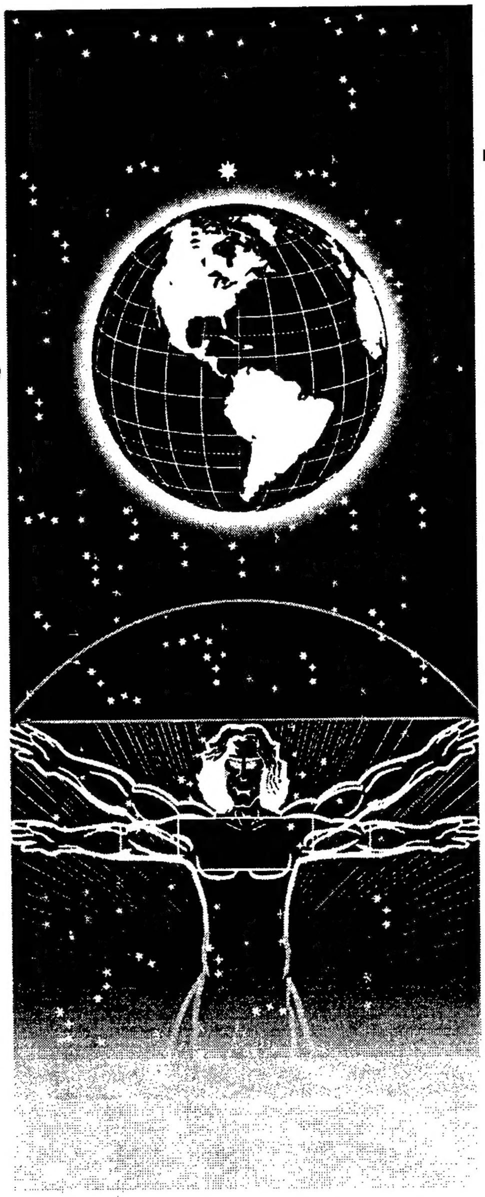

UNITED STATES AIR FORCE RESEARCH LABORATORY

PORTABLE EYE-TRACKING SYSTEM USED DURING F-16 SIMULATOR TRAINING MISSIONS AT LUKE AFB: ADJUSTMENT AND CALIBRATION PROCEDURES

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November 1998

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This paper has been reviewed and is approved for publication.

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A portable eye-tracking system has been employed at Luke Air Force Base, AZ, for use during F-16 B-course simulator training missions. Proper headband adjustment and accurate calibration of the eye-tracking system allows the instructor to see exactly where the student is looking throughout the training mission. This paper describes the components of, and the correct adjustment procedures for, the Elmar Vision 2000 system. These procedures were developed in order to allow the system to successfully be transitioned to the user; namely, the simulator operator.

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PREFACE

This work was conducted under Work Unit 1123-B0-01, Warfighter Training Research Support, Contract F41624-97-D-5000 with Raytheon Training Systems. The Laboratory Principal Investigator was Dr Byron J. Pierce; the Laboratory Contract Monitor, Mr Jay Carroll.

This effort is part of an Air Force Research Laboratory, Human Effectiveness Directorate, Warfighter Training Research Division (AFRL/HEA) program to transition valuable technology, namely eye-tracking technology, to the warfighter training arena.

PORTABLE EYE-TRACKING SYSTEM USED DURING F-16 SIMULATOR TRAINING MISSIONS AT LUKE AFB: ADJUSTMENT AND CALIBRATION PROCEDURES

INTRODUCTION

This manual provides basic information on the operation of the portable eye-tracking system. Simple step-by-step procedures are described allowing the user to adjust, calibrate, and operate the system quickly and accurately. The manual also describes the portable eye-tracking system components, provides instructions for all connections, and explains the necessary steps to achieve accurate measurement of eye position and monitoring. A brief explanation of the principles behind eye tracking is found in the last section of this manual. A more extensive description of the system may be found in the El Mar Vision 2000 manual.

Although the portable eye-tracking system has been designed for ease of use and reliability, problems can and will occur. Fortunately; the corrective actions required are often straightforward and can be made quickly and efficiently. In order to help the user become more confident with system operation, we have made every effort to describe and illustrate the most common problems and the appropriate actions required to solve them. With experience and practice, the eye-tracking system can be adjusted, calibrated, and operating in just a matter of minutes.

EYE-TRACKING SYSTEM COMPONENTS

The complete portable eye measurement system as shown in Figure 1 consists of an adjustable headband, the main processor unit, a hand-held keypad, and a compact monitor. The complete system weighs less than 30 pounds and is easily transportable in a single case.

Adjustable Headband

The primary function of the headband is to provide a stable support for the eye measurement sensor, beamsplitter, and the centrally-mounted scene camera. The headband also supports a standard military microphone and a pair of external earphones. The headband with all attachments weighs approximately 300 grams. The headband has two ratchet-like adjustment knobs located at the top and back of the headband and can be adjusted to comfortably fit almost any head size. When properly adjusted, the headband can be comfortably worn throughout any simulator training mission. An improperly adjusted headband can lead to hot spots or other discomforts leading to shortened usage time. A procedure for positioning and adjusting the headband can be found in paragraph four of the **Start-Up Procedures Section**.

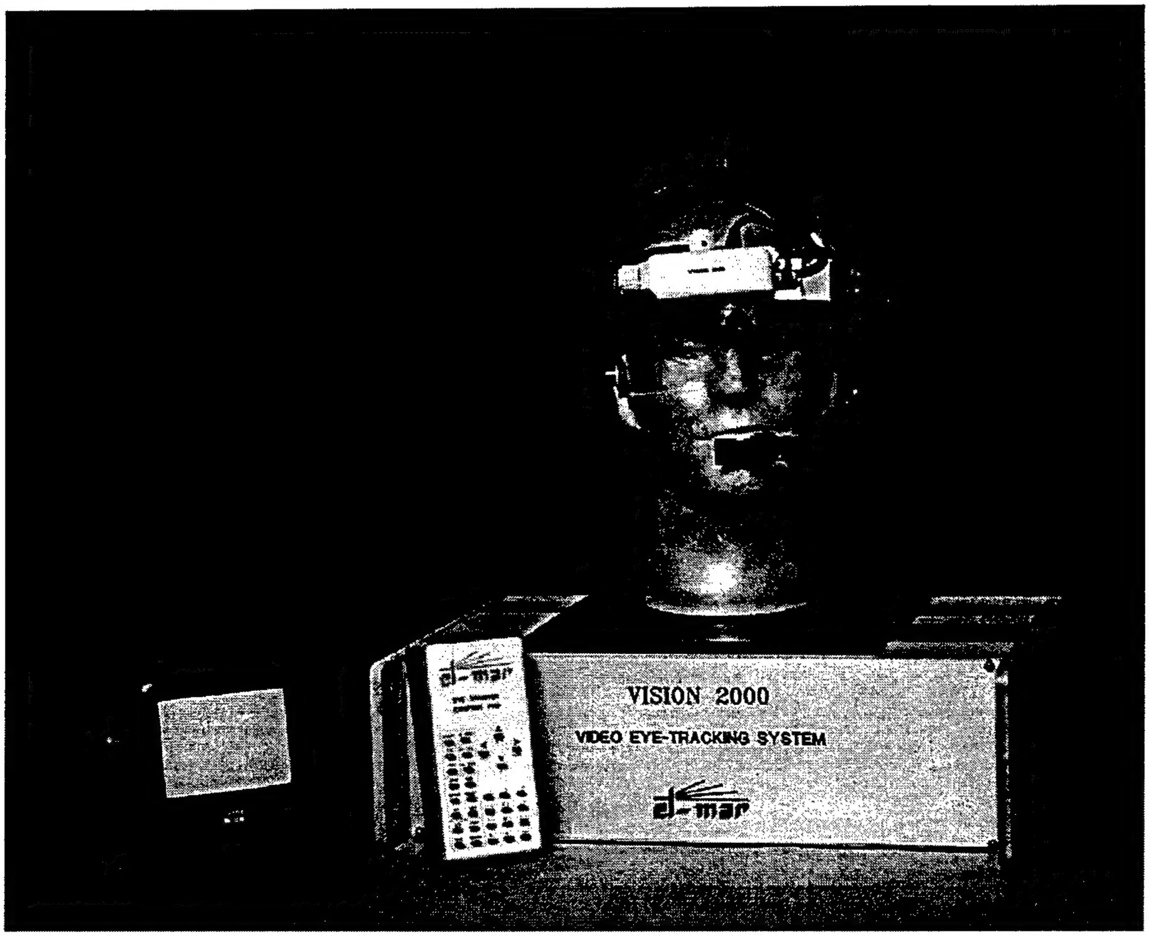

Figure 1. Portable Eye-Tracking System.
Main processor unit, hand-held keypad, display monitor, and adjustable headband with components.

Main Processor Unit

The main processor unit is a standalone device, controlling all functions of the eye-tracking system. The primary control functions include eye position and pupillary estimation, eye calibration, video display, cursor generation and control, and connections to a VCR and PC. All standard functions of the main processor unit can be accessed and controlled via the hand-held keypad. Several advanced settings are accessible via a PC through a serial port connection. Program and eye-tracking parameters are stored in electrically erasable, programmable memory. Program updates can be loaded from any DOS-based PC to the main processor unit via one of two serial ports. The serial port can also be used to graphically view actual eye movement data via connection to a PC.

Using the hand-held keypad, various system and control parameters can be set for a specific training environment or condition, such as calibration angles, scene camera focal length, and cursor style. The hand-held keypad can also be used to make small changes in cursor position during operation. Data from the portable system are recorded onto a hi-fi stereo VCR tape recorder. These data include video from the scene camera and cursor, as well as encoded audio data comprising horizontal and vertical eye position, pupillary size, blink and system status information, and frame count. The other audio channel can be used to record voice communications. Eye-position data are stored at a rate of 60 Hz. Additional stored data include the recording of event/playback markers, system status, and frame counter information. The hand-held keypad allows the user to mark "significant events" on the videotape for later review, without having to search the entire tape during playback.

Hand-Held Keypad

The hand-held keypad shown in Figure 2 controls the basic functions of the portable system. When preparing to eye track a subject, the keypad is used to select and control various functions of the main processor unit required during the initial adjustment and

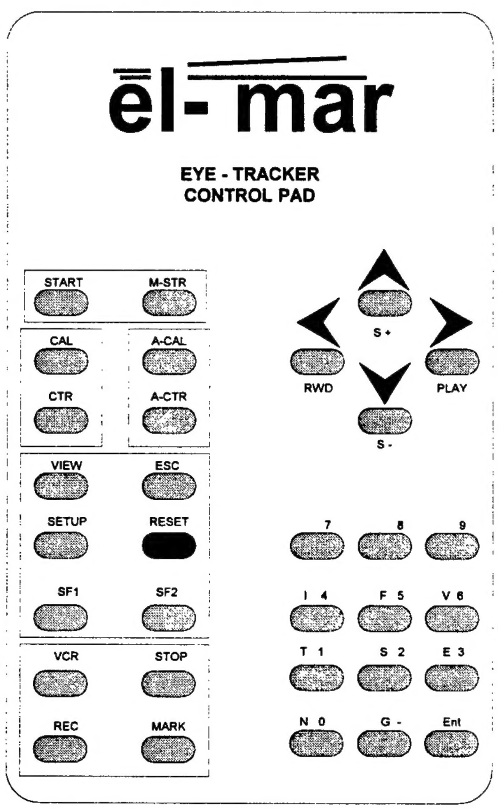

Figure 2. Hand-Held Keypad

calibration of the eye measurement system. When tracking a pilot, the keypad can be used to make small shifts in cursor position through the left-right and up-down cursor control keys on the keypad. Further explanation of keypad operation is located in the **Start-Up Procedures Section**.

Video Display and Recording Capability

The portable system includes a compact monitor used for eye and scene alignment, calibration, and for observation of the user's gaze response. A standard VHS recorder may be used to record the eye position superimposed on the scene. To simplify operator use, the functions of the recorder can be controlled via the hand-held keypad.

The Scene Camera

A black-and-white infrared sensitive scene camera (Elmo Model EM 102-BW) is mounted between the eyes on the headband. For most applications, the scene camera is mounted level with the eyes. When used with aircraft having collimated head-up displays (HUDs), the scene camera must be mounted in the pupillary plane, directly between the eyes, to minimize parallax. Any of five interchangeable lenses may be used with the scene camera. Available lenses include fields of view of approximately 102°, 90°, 70°, 45° and 22°. Each lens has separate adjustments for focus and aperture size. Often, the choice of a lens is determined by balancing the requirements of field of view (FOV) and detail, considering that as FOV increases, detail decreases. The system currently employs the 4 mm focal length, 90° FOV lens.

The relationship between scene camera focal length in millimeters and FOV is provided below.

102° FOV –	3.0 mm
90° FOV –	4.0 mm
70° FOV –	5.5 mm
45° FOV –	7.5 mm
22° FOV –	15.0 mm

CONNECTIONS

Main Processor

The following steps should be performed prior to applying power to the system. Refer to Figure 3 for the locations of the main processor unit connections and switches. Before making any cable connections, make sure that the power supply switch for the main processor unit is in the **OFF**, or **Ø**, position. The power switch for the scene camera module may be left in the **ON** position.

Lastly, confirm the toggle switch labeled "**Run/Load**" is in the "**Run**" position. For those units with a "**Run/Analyze**" toggle switch, place the switch in the "**Run**" position.

1. Plug the hand-held keypad connector into the matching multi-pin DIN socket marked "**KBD.**"

2. Two black cables extend from the headband. The DB-15 pin male connector corresponds to the eye measurement sensor and the multi-pin circular plug corresponds to the scene camera. Be sure to remove any twist or loops from all cables before connecting to the main processor unit.

   - Plug the DB-15 pin male connector from the eye sensor into the corresponding bottom left-most female connector marked "**CAMERA**" on the processor unit.

   - Attach the multi-pin circular plug from the scene camera into the matching jack labeled "**CAMERA**" located in the black rectangular scene camera box. This box may be found on the upper right area of the processor unit.

3. The miniature BW Video monitor requires both power supply and video connections. From the cable attached to the monitor, connect the circular male mini-power supply plug to the corresponding jack labeled "**12V**" located to the left of the black scene camera module. Connect the male RCA phone plug to the matching jack labeled "**VIDEO**" located under the scene camera module.

4. With the main power supply switch in the **OFF**, or **Ø,** position, connect the AC power cord to the AC input connector located at bottom right-hand corner of the processor unit.

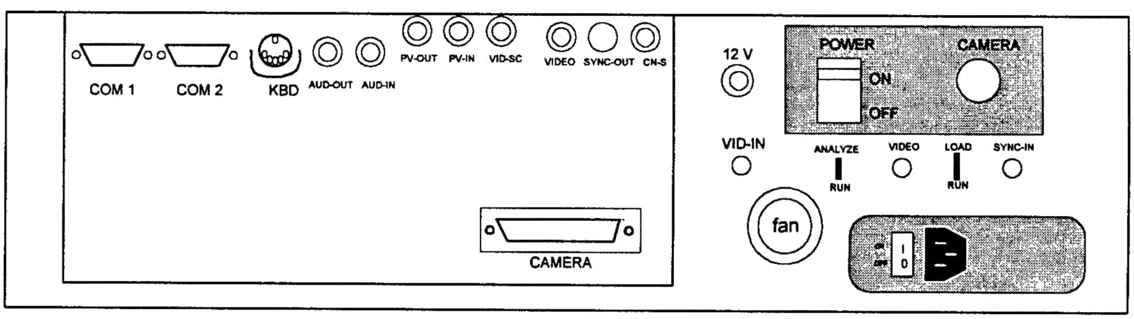

Figure 3. Main Processor Unit

Voice Communications

The headband includes a fully compatible microphone and headset that connects directly to the simulator communications system via a MIL-standard connector plug. The external headphones connect to an audio jack located near the side of the head via a mini-audio plug while the microphone is connected via a two-pronged jack.

Recording voice communications between instructor and pilot may be accomplished with the RCA female phono jack, located at the end of the audio cable. A compatible plug and shielded cable should then be connected from the RCA female phono jack to the **Right Channel Line 1 Input** of the VCR.

VCR and Monitor

A high quality Sony Hi8 mm VCR is included with the portable eye-tracking system. Recording audio and video aspects may be beneficial for later review of critical mission elements by the instructor and/or the student. A second large-screen video monitor may also be connected to the processor unit allowing easier viewing and better scene detail.

Several VCR functions such as Start/Stop, Record, Playback, and Mark can be controlled from the hand-held keypad. These functions can also be accessed through the hand-held infrared remote control.

VCR and Monitor Notes:

- To control the VCR through the keypad, an additional cable must be connected from the **Control S/L** jack located on the top row of the processor unit to the Control S or L input jack on the VCR. Further, the Control-S or L feature must be enabled through the **Setup** menu from the hand-held keypad. The Sony Hi8 recorder requires the Control-L protocol while the Sony SuperVHS recorder requires the Control-S protocol.

- To attach the VCR to the system, connect a 72 Ω impedance coaxial cable from the BNC "**Video**" output connector located on the top row of the processor unit to the **Line 1 Video Input** jack located on the VCR.

- To connect a monitor to the VCR, attach a suitable length of 72 Ω impedance coaxial cable from the VCR **Line 1 Video Output** to the **Video Input** of the monitor.

1. From the VCR control panel, press the Input Select Switch until **Line 1** or **L1** appears on the VCR display panel. As long as the VCR remains connected to an AC power line, any VCR settings will remain.

2. If no VCR is used, connect a suitable length of cable from the BNC Video output connector, located on the top row of the main processor unit, directly to the input of the Video monitor.

Figure 4 summarizes the connections between the various components of the system.

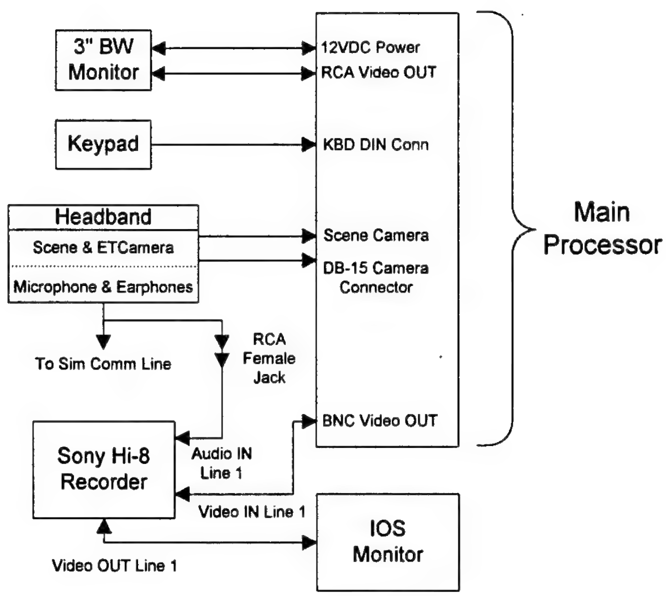

Figure 4. Portable Eye-Tracking System Connections

START-UP PROCEDURES

Following the steps in this section allows one to successfully capture the pilot's eye characteristics with respect to surrounding light levels as well as calibrate the pilot's eye position with respect to the scene.

<u>Operation and Initial Adjustment</u>

1. Before turning the system **ON**, check and make sure that the **RUN/LOAD** and **RUN/ANALYZE** toggle switches are in the **RUN** positions, the scene camera rocker switch is in the **ON** position, and that all cables are properly connected.

2. Turn the main power rocker switch to the **ON** or **1** position. During power up, the system will perform a self-test while the message **EL-MAR, Inc. Vision 2000** will appear across the top of the video monitor screen. When power to the scene camera module is **ON**, a small power lamp or a portion of the rocker switch will be illuminated green.

3. Two versions of the headband are currently available and are distinguished by the mounting of the scene camera. The earlier version has the scene camera was fixed to the headband frame. The more recent version allows the scene camera to be swiveled and moved independently of headband position. The advantage of the swivel mount is that it allows alignment of the scene camera without having to change headband position. The fixed-scene camera mount is shown in Figure 5 while the swivel-mount configuration can be seen in Figure 6.

4. The following instructions apply to both configurations. Generally, before placing the headband on the pilot, fully expand the headband by turning the top and back adjustment knobs completely counterclockwise. Place the headband on the pilot so it sits directly above the eyebrows. See Figure 5 and/or Figure 6 for an example of proper headband placement for both the fixed and swivel mount. Adjust fit with the knob on the horizontal band (located at the back of the head) so the unit is snug, yet not uncomfortable nor overly tight. Next, tighten the vertical band (with the knob on top of the head) just enough so it supports the position of the headband above the eyebrows. Be sure not to tighten the vertical band too much--the distance between headband and eyebrow should not change.

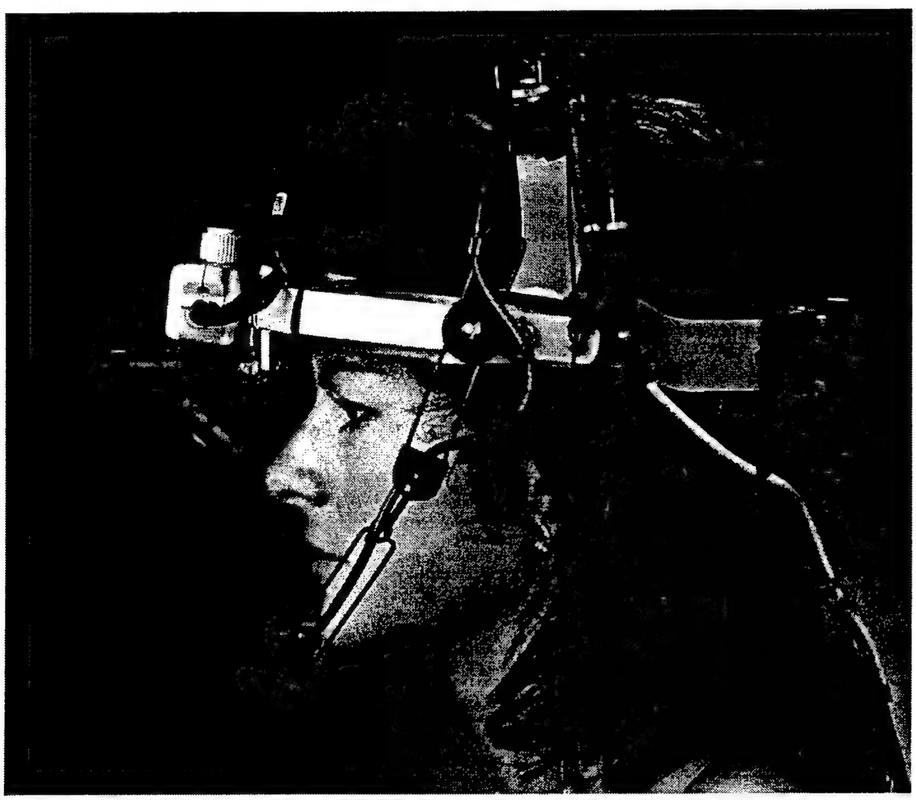

Figure 5. Headband Position with Fixed-Scene Camera Mount

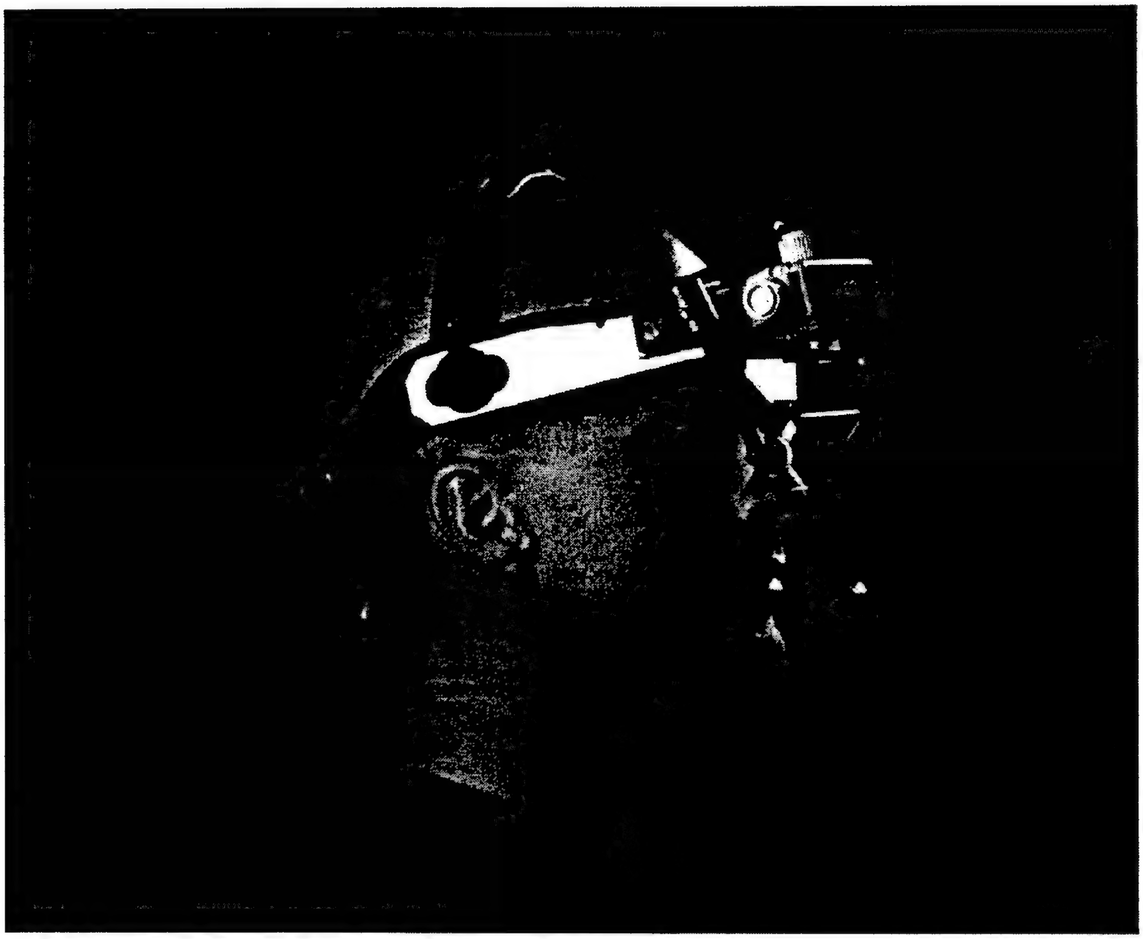

Figure 6. Headband Position with Adjustable-Scene Camera Mount

5. Pressing the **VIEW** key on the hand-held keypad allows one to switch the picture displayed on the monitor between the view of the pilot's eye and the view of the scene. Press **VIEW** so that the view of the scene is displayed on the monitor. With the fixed mount, adjust the position of the scene camera by minor repositioning of the headband. With the swivel mount, adjust the scene camera by grasping and manually repositioning it from above. In either case, adjust the position of the scene camera until the scene, as seen from the video monitor, appears straight.

6. Locate the position of the eye by pressing the **View** key on the hand-held keypad. Next, rotate the clear, rectangular plastic beamsplitter by rotating the support bracket until the pupil appears centered within the view box of the monitor. **Never directly rotate and or touch the beamsplitter itself**. The beamsplitter will not break. However, it is susceptible to fingerprints, smudges, and scratching. Avoid these problems and minimize mechanical stress by gently rotating the beamsplitter support bracket, which is closest to the black support rod.

To locate the position of the eye, press the **VIEW** key on the hand-held keypad.

*Note: Pressing the **VIEW** key alternates between the eye and the scene camera image.*

Rotate the beamsplitter by carefully gripping the support bracket until the pupil of the eye is vertically centered within the view box. To center the pupil horizontally, turn the knob on the right side of the gray plastic housing box above the eye. Centering the pupil is not an exact science and close enough is sufficient. Figure 7 below shows an example of the pupil properly centered within the view box.

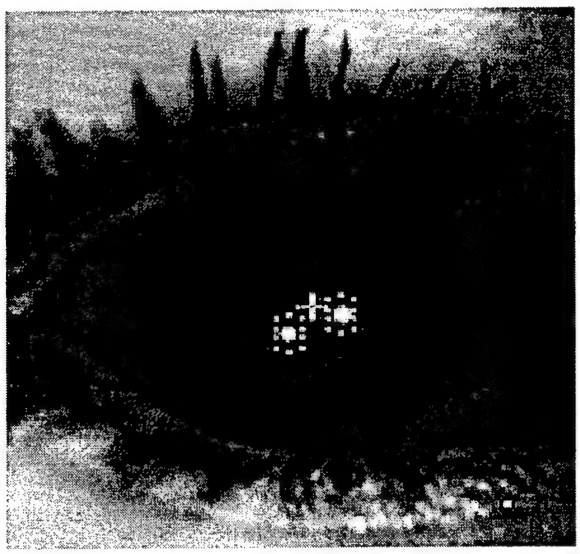

Figure 7. Centered Eye Position

Infrared image of the eye centered within the view box showing ideal location of the pupillary center estimate (the cross) and two bright corneal reflections surrounded by dotted boxes.

7. Adjust the focus of the eye camera. The focus knob is located on top of the eye-tracker housing box. Turn it to focus or minimize the size of the two corneal reflections on the image of the eye. A focused reflection appears as an oval bright spot surrounded by smaller bright dots as shown in Figure 8. An unfocused reflection appears as a bright spot without the surrounding dots. **Important**, be sure to focus the reflections, and not the eye itself. If only one reflection appears on the eye, loosen the headband slightly and move it up on the forehead just enough so that two reflections come into view.

Auto-Start

1. When the pupil is centered in the view box and the reflections are focused, ask the pilot to look straight ahead while you press **START** on the hand-held keypad. Pressing **START** instructs the system to automatically adjust the intensities of the infrared (IR) Light Emitting Diodes (LEDs) and the image contrast level so it is optimal for the person's eye and surrounding light level. During the automated startup mode, the process may repeat itself up to six times (the eye picture will flash in and out up to six times) and can be terminated at any time by pressing the **ESC** key. If successful, a "**START OK**" message will appear at the bottom of the view box on the display monitor. If the "**START OK**" message appears, proceed to the Calibration Section.

2. In some cases, the system may have difficulty successfully completing the automatic startup process as in Step 1 above. If the auto start process fails, a "**START REPEAT**" message will appear at the bottom of the view box on the display monitor. If this occurs, ask the pilot to look straight ahead, but then have the person move his/her head slightly to the left or right just enough so that the corneal reflections move slightly off the pupil crosshair position but not onto the white of the eye. An example of this technique is shown in Figure 8. At this point, press the **START** key again. If the "**START OK**" message appears, proceed to the Calibration Section. If "**START REPEAT**" appears, follow the procedures below for a manual start.

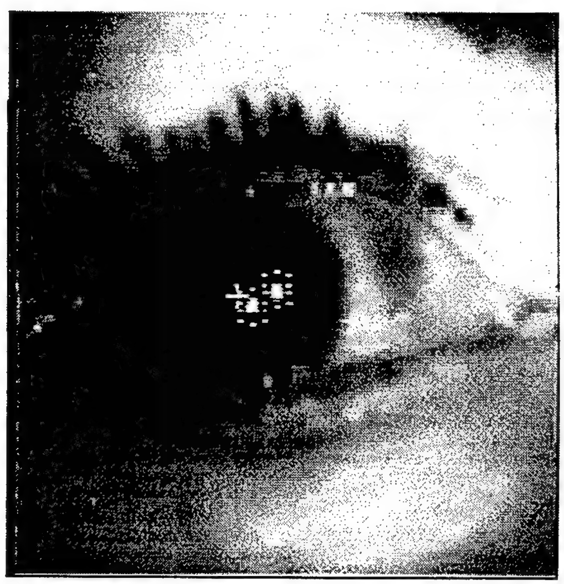

Figure 8. Offset-Startup Technique.
Position of Eye and Corneal Reflections during the Offset-Startup Technique.
A shift in head position causes the corneal reflections
to move off of the pupillary center cross.

Manual Start

The manual startup process is very effective whenever the auto start fails or when individual intensity control of the infrared LEDs is desirable.

If the auto-start procedure in Steps 1 or 2 did not result in a "**START OK**" message, then proceed with a manual start.

1. Ask the pilot to look straight ahead. As soon as his/her eye appears to be resting, press **M-STR** on the keypad. A large crosshair will appear in the center of the display.

2. Center the pupil on the large dashed crosshair by rotating the beamsplitter support bracket. Rotate the beamsplitter until the pupil is centered vertically within the view box. Center the pupil horizontally by turning the knob on the right side of the plastic housing box above the eye.

3. Press **M-STR** again. A picture very similar to what is shown in Figure 9 will appear. The numbers 1 and 2 along with a respective line of dots represent the intensity of each emitter.

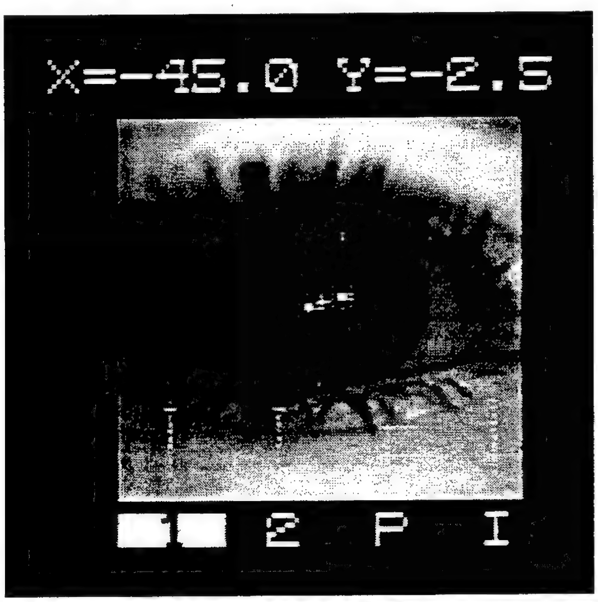

Figure 9. Manual Start (**M-STR**) Display Mode

4. The number "**1**" will be highlighted at the bottom of the monitor. Use the Up or Down arrow key on the hand-held keypad to increase or decrease the infrared level for that emitter.

5. To adjust the intensity of the second LED, press the Right arrow which will highlight the number "**2**" at the bottom of the monitor. Again, use the Up and Down arrow control buttons to either increase or decrease the LED infrared intensity.

Adjustment Tip:

- As the intensity of the LED is changed, the image brightness will change accordingly as well as the bar graph above the LED number.

6. After performing either Steps 4 or 5, try pressing the **M-STR**. If the message "**START OK**" appears, you may proceed to the calibration section. To adjust image contrast, press the Right arrow key until the highlight bar is on the "**P**" for pupil position. Image contrast between can either be increased or decreased by pressing the up or down cursor control keys. Generally, only small changes in image contrast are required. When finished, press the **M-STR** key and wait for the "**START OK**" message to appear. You may either proceed to the Calibration section below or, if time permits, perform an Auto-Start to optimize the settings, then calibrate.

Calibration

The calibration procedure is always required as it defines the relationship between a known target angle and eye position. The best calibration is performed quickly but accurately. A good calibration defines the accuracy and extent to which useful feedback can be provided by the instructor to the student.

1. Place the calibration chart at the proper distance from the pilot's eye point and make sure the chart is straight and level.

   Note: If the scene camera lens has been changed recently, make sure that the current focal length matches that in the ***Setup*** *Menu. Follow the* ***Setup Menu*** *procedures if the lens has been changed.*

2. Ask the pilot to keep his/her eye steady when looking at each calibration point.

3. Press the **VIEW** key on the hand-held controller until an image of the eye appears on the monitor.

4. Press **CAL** key and notice the message on the monitor, "**POINT 1.**"

5. Ask the subject to look at calibration Point 1. As soon as his/her eye appears to be stable, press **CAL**, which will record the position of the eye with respect to calibration Point 1.

6. When the computer has finished recording at that position (approximately two seconds), "**POINT 2**" will be displayed on the monitor. Ask the pilot to look at Point 2. As soon as the eye rests on **Point 2**, press **CAL,** and so on, until all 10 points have been recorded. After Point 10 has been recorded, the message "**CAL OK**" should appear on the monitor. If so, go on to Step 7. If "**CAL REPEAT**" appears instead, skip down to Step 8.

Calibration Notes:

a) If more than three seconds have passed from the time the pilot rests his/her eye rests on the point and the time you press **CAL**, the eye may have unconsciously drifted from the point. If such a delay occurs, ask the pilot to look at **Point 1** again before pressing **CAL**. This will help the pilot consciously reposition his/her eye, which will result in a more accurate calibration.

b) Watch the pupil crosshair and the corneal reflections during the calibration and note if one or more of them disappears or flickers at more than one point.

c) If you notice the subject's head moving as he/she moves the eye to the next point, press **ESC** on the hand-held keypad, ask the pilot (again) to keep his/her head still, and go back to Step 4.

Informational Note:

After calibration, you now know where the eye is with respect to the head, that is, assuming the headband has not slipped on the head. In addition, you also know where the head is, based on the image from the scene camera--this also assumes that the scene camera has not moved from its mount. In order to know where a person is looking, you need to perform a final alignment between head and eye position. To perform this alignment, ask the person to look at a central point while you electronically move the position of the cursor to the same point. After alignment, you will know exactly where the person is looking. The following steps describe this procedure.

7. If the "**CAL OK**" message appears on the monitor, switch to the scene camera image by pressing the **VIEW** key. A small, bright crosshair will be superimposed onto the scene. Press **CTR**. Use the arrow keys on the hand-held keypad to position the crosshair on top of the 3-8 center point on the calibration chart. Now ask the subject to look at the center point. As soon as the eye appears to be resting, press **CTR** again. The crosshair, superimposed onto the scene, will now correspond to the subject's eye position. Skip down to Step 9.

8. If the message "**CAL REP**" as shown in Figure 10 appears after Step 6, consider the following items and follow the appropriate procedure:

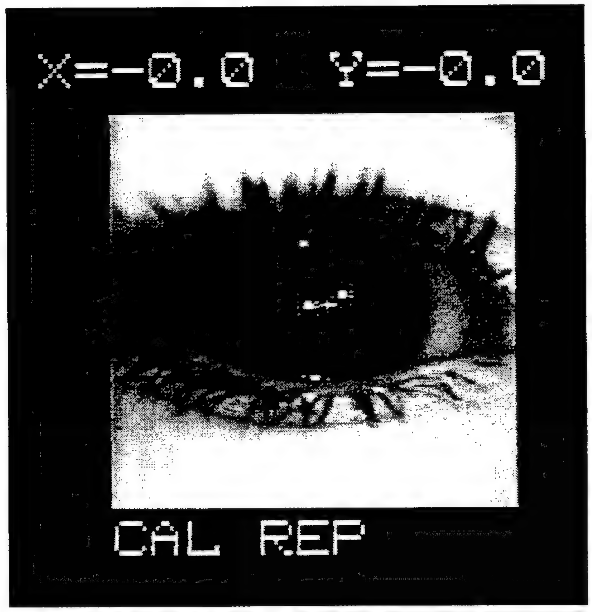

Figure 10. Calibration Repeat (**CAL REP)** Message

a) Did the pupil crosshair or either of the corneal reflections disappear at more than one point? (For example, did the pupil crosshair disappear or flicker at calibration points 6 and 7?) If so, press **VIEW** to ensure the pupil is still centered within the view box--two reflections appear on the eye image, and the two reflections are circled by small dots. If not, center the pupil, adjust the headband so two reflections appear, or focus the reflections (whichever is necessary) as previously explained in **the Start-Up Procedures**. Then proceed with an Auto-Start.

b) Was the subject's eye unstable at any point during the calibration process? For instance, was the eye moving? did the person blink? or did the eyelid droop after you pressed **CAL** at one or more calibration points? If so, and nothing in (a) above applied, then repeat the calibration process. This time, you may want to ask the pilot to blink while moving the eye to the next point. If the eyelid drooped over the eye during calibration, you may need to tell the person to open his/her eye very wide at each point.

c) Did the subject keep his/her head still during the calibration? On occasion the person may unknowingly move their head from point to point and, in fact, you may even notice the pilot doing this. If so, simply remind the pilot not to move his/her head, and repeat the calibration.

9. After you have successfully calibrated the pilot's eye position to the points on the calibration chart, remove the chart from the simulator. Let the pilot know that you can adjust the headband for comfort during the training mission, if necessary.

Figure 11 provides a summary diagram of adjustment procedures.

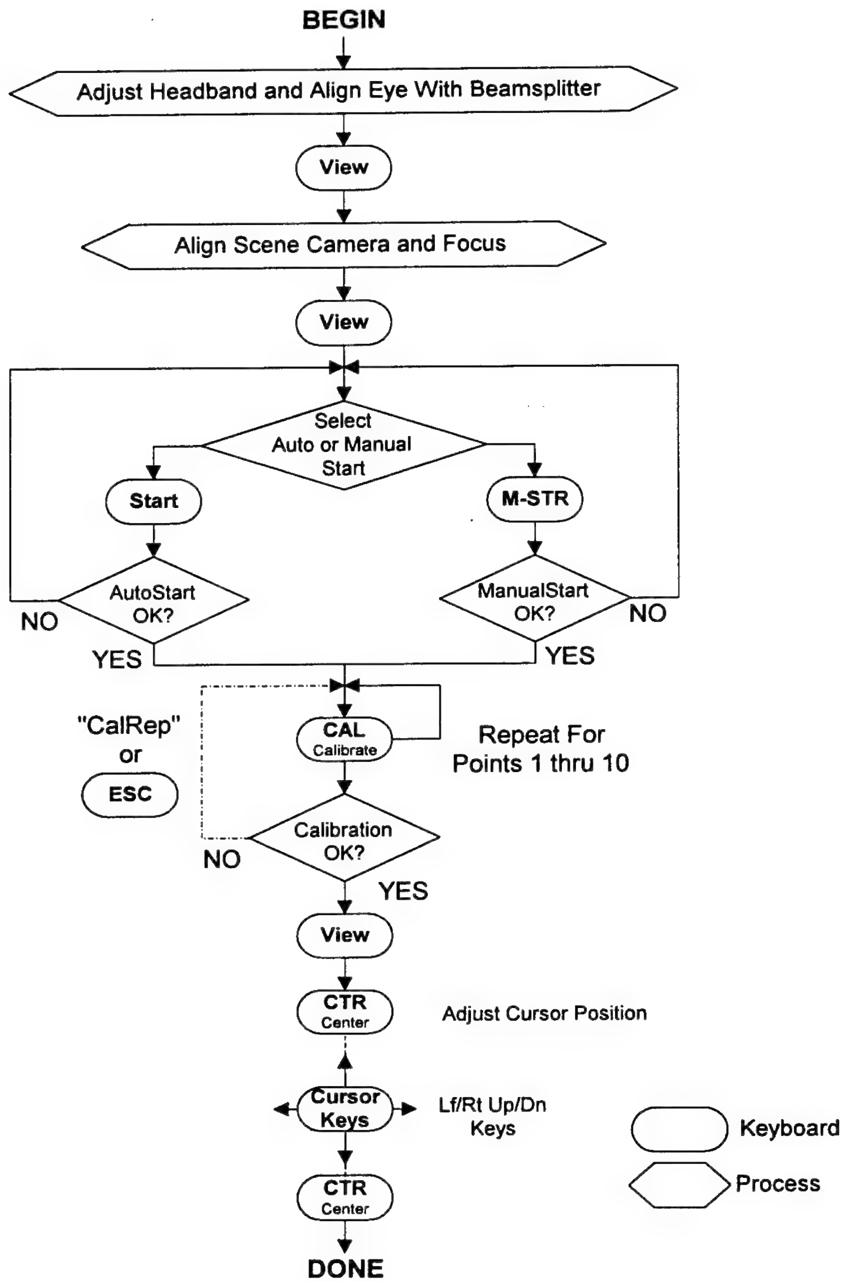

Figure 11. Summary Diagram of Adjustment Procedures

SETUP MENU

The Setup Menu provides access to a number of program settings that are available by pressing the **SETUP** key located on the hand-held keypad. A summary of the setup menu steps is shown in Figure 12.

Setting changes can be either temporary or permanent. Temporary changes remain in effect only while power to the system remains ON. Permanent changes remain in effect until changed and are not affected by power to the system.

The only changes that may be required are those related to the focal length of the scene camera lens, the use of either Control-S or Control-L, and calibration angles. All other settings should not require modification.

The keypad cursor keys can be used to select among the various program parameters. Upon selecting a parameter for modification, repeated presses of the **ENTER** key can be used to scroll through the available program values.

If modifying the calibration angles, negative angles, i.e., those to the left of center or below the zero horizontal line, must be entered by first pressing the negative sign (-) key followed by the remaining digits. Each calibration angle must be entered as if having been multiplied by a factor of 10. For example, an angle of 5° would be entered as "50" and a 10° angle would be entered as "100." Again, a negative angle is entered by first pressing the (-) followed by 10 times the actual angle. For example, if you wish to enter "-10°," press "-100."

Note: The **ESC** key can be used to leave the Setup Menu at any time without changes.

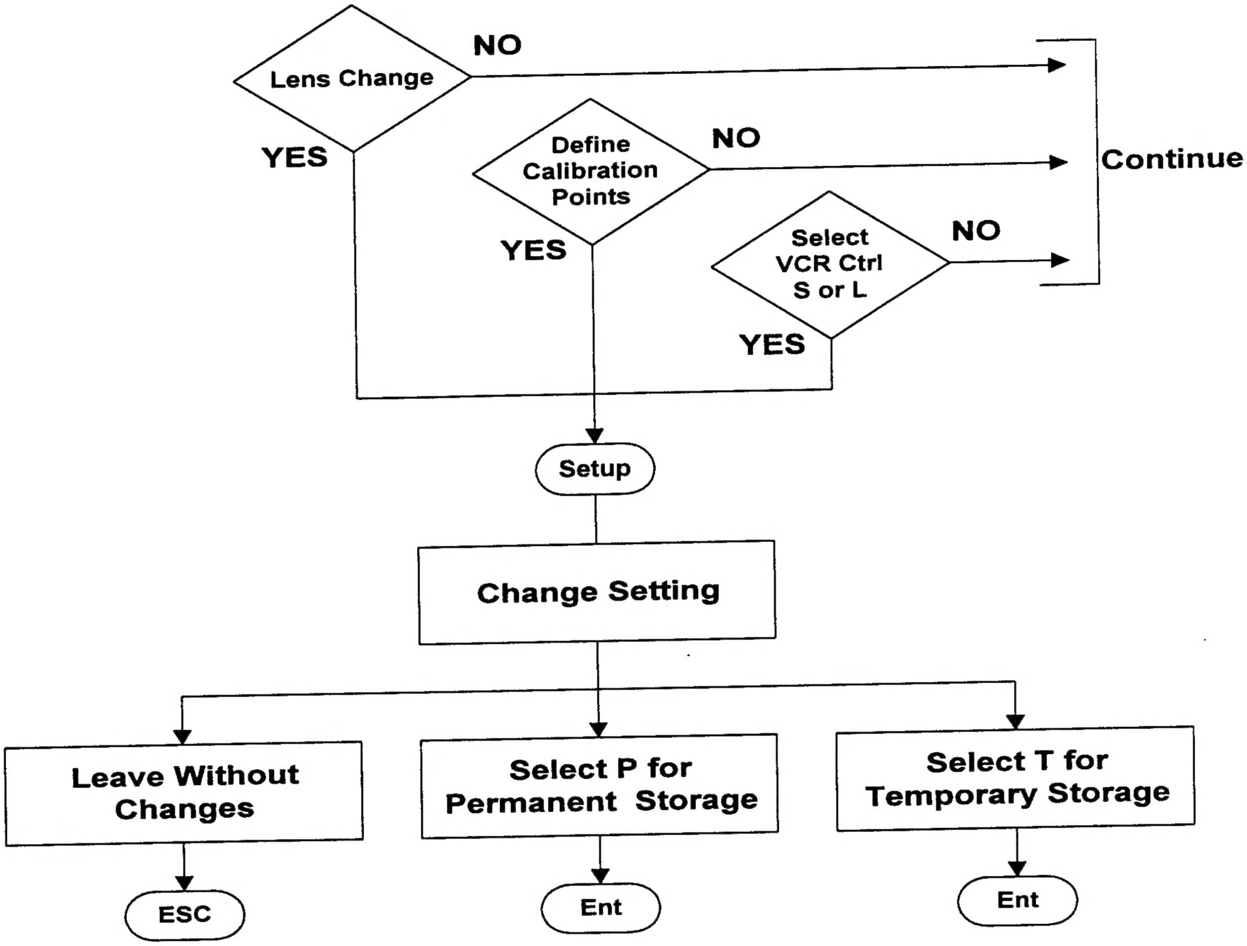

Figure 12. Setup Menu Procedure

MAINTENANCE

General Maintenance

Under normal use, the eye-tracking system should not require regularly scheduled maintenance. Periodically, however, the cables and connectors to the main processor unit should be checked. Generally, when problems have occurred, they have often been related to loose BNC-type connectors. Because the headband components are subject to continual movement, they should be visually inspected prior to each mission and checked periodically for looseness.

Beamsplitter Cleaning

The beamsplitter should not require any regularly scheduled maintenance. Dust or fingerprints or even minor scratches on the beamsplitter surface will not adversely affect the ability of the system to track the eye. Fingerprints and or other surface smudges may make it difficult, however, for the wearer to see clearly through the beamsplitter. In this event, it may be necessary to clean the beamsplitter surface. Although the beamsplitter is constructed of an unbreakable polycarbonate plastic with over twenty specialty coatings, it can be damaged due to improper cleaning.

To avoid permanent damage to the beamsplitter, NEVER cleaned it with alcohol or alcohol wipes.

Clean the beamsplitter with either a specialty lens cleaner or water along with a clean, soft, cotton or silk cloth. The surface of the beamsplitter should first be wetted and then gently rubbed between the fingers then dried with the cloth.

PRINCIPLE BEHIND THE EYE-TRACKING SYSTEM

This eye-tracking system is based on the dark pupil principle. It provides estimates of horizontal and vertical eye position and pupillary size at a rate of 60 Hz. The system uses an estimate of pupil center and compares this measurement with the positions of two corneal reflections. The virtual images formed by the corneal reflections are the result of two noncollimated infrared Light Emitting Diodes located within the plastic housing above the eye. The infrared LEDs are pulsed at 60 Hz and homogeneously illuminate the eye with less than 300 $\mu w/cm^2$ of energy. Because the infrared sources and the imaging optics are not coaxial to the eye, the pupil remains dark. A shatterproof plastic beamsplitter located below the line of sight of the right eye redirects the reflected IR light from the eye to a two-dimensional charge coupled device (CCD) array located in the plastic housing above the eye. A set of knobs on the plastic housing allows the user to focus and translate the image of the eye. Previously, Figure 7 exhibited an infrared image of the eye showing the two corneal reflections (two bright dots) and an estimate of the dark pupil center (the crosshair).

The system can measure eye movements up to ±45° horizontal (H) and up to ±35° vertical (V). It has an accuracy of better than ±0.5° for changes in eye position less than ±15° H and V that decreases to ±1° at the limits. The resolution of the system is better than 0.2°. The pupillary corneal difference method allows one to distinguish between headband movement versus changes in eye position. Without this compensation, if the headband slipped on the pilot's head, it would look as though the person actually moved his/her eye. Headband slippage of only 1 mm would appear equivalent to an eye movement of up to 10°. This system can tolerate headband slippage up to 5 mm without affecting the accuracy of the eye position data.

FURTHER INFORMATION

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